A GENERAL-PURPOSE ANTENNA TUNING UNIT

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MOST AMATEUR STATIONS have a number of antennas available, some resonant and others of random dimensions, all of which may require some degree of impedance transformation before they can be connected to the station transmitter. In my case there was a requirement to match end-fed antennas, balanced antennas and the occasional resonant antenna for operation on all bands from 1·8 to 28MHz.

The tuning unit to be described is one version of the popular "transmatch" featured for many years in the *ARRL Handbook*. Other features have been added to permit the selection of different antennas as well as the facility to ground all inputs when the station is not in use.

The transmatch design

Anyone who has seen several editions of the *ARRL Handbook* will be aware that the "ultimate transmatch" has, over the years, undergone a number of circuit changes. The original design, Fig 1(a), used either a differential or a split stator input capacitor. The differential capacitor is less common than the split stator and has one section at a maximum capacitance while the other section is at minimum capacitance. This has the effect of providing a synthetic sliding tap on the inductor L, whereas the split-stator capacitor tunes the inductor L, but maintains the tap centrally. The use of a dual-type input capacitor for harmonic suppression lost all credence some years ago and the circuit was amended to the simpler T-match of Fig 1(b). This circuit is that of a highpass filter and provides no suppression of harmonics. More recently the "SPC" transmatch has emerged with a dual-output capacitor and is supposedly capable of providing a degree of harmonic suppression. In any event all three designs perform the task of matching a range of impedances quite successfully.

With the advent of ssb and linear amplifiers and, more recently, solidstate transmitters with built-in lowpass filters, harmonic suppression is not the problem it was when using Class C a.m power amplifiers. It was therefore decided in the interest of simplicity to adopt the T-match variant of the transmatch in this general-purpose antenna tuning unit (Fig 2).

Component selection

New components suitable for use in antenna tuners are not readily available, so the use of surplus components is the most economical answer. Fortunately the values of capacitors required are not too critical, and almost any high-quality wide-spaced variable capacitor can be put to use. Ideally a value of between 200pF and 400pF is suitable, and a number of surplus Johnson and Eddystone 390pF units have been seen over recent years. These units have ceramic end plates and are tested to 2000V dc working. If in doubt, aim at a plate spacing of at least 1·5mm between the stator and rotor plates; this is necessary to cope with the high voltages which can be developed when matching high-impedance long wire antennas.

Inductors can be either fixed with a number of taps selected by a rotary switch, or variable such as the roller coaster which allows maximum flexibility in matching. Roller coasters come in a variety of different shapes and sizes, but in general are not available in other than small numbers and one-offs.

All switches used are of the "Yaxley" type and use ceramic wafers; large numbers of this type of switch can often be found in junk boxes at rallies for a few pence, and several switches can be broken down and reassembled to achieve the desired configuration. Paxolin wafers can be used, though they are not as good as the ceramic type.

The antenna selector switch uses a double-spaced switch unit giving six stops/revolution rather than the usual 12. Wafers are modified by removing alternate contacts, reducing the likelihood of arcing between them.

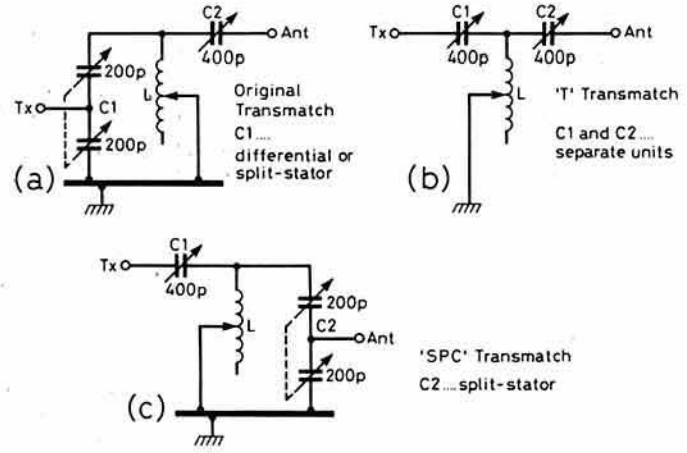
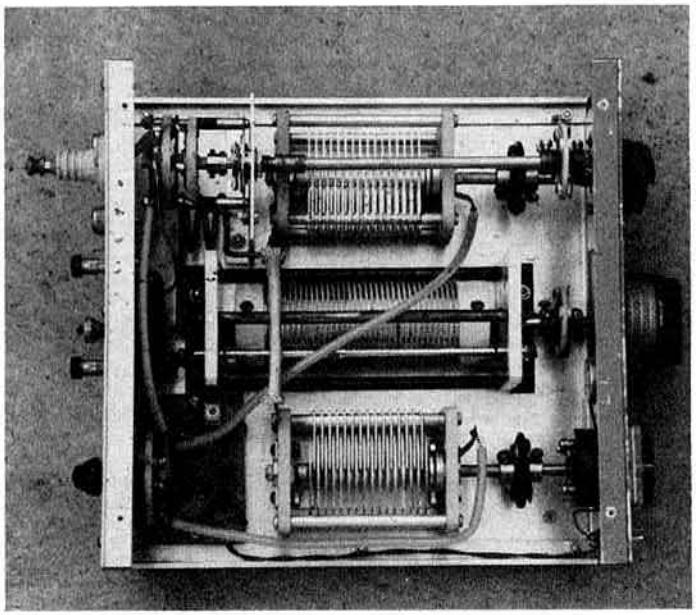


Fig 1. Variations of the "Ultimate transmatch". (a) Original transmatch: C1 differential or split stator. (b) T-transmatch: C1, 2 separate units. (c) SPC transmatch: C2 split stator



Internal view of the tuning unit using a roller-coaster

Mike Grierson was born in 1945 and took up amateur radio in 1958 constructing small crystal and battery valve receivers. After a period of self-tuition he passed the RAE at the age of 15 and was subsequently licensed in 1964. He has followed a simple rule of not operating on any amateur band without first constructing homebrew equipment for that band. Over the years he has constructed numerous receivers, transmitters and items of ancillary equipment for all bands from 1·8 to 144MHz. With no formal training or professional qualifications in electronics, he pursues amateur radio strictly as a hobby.

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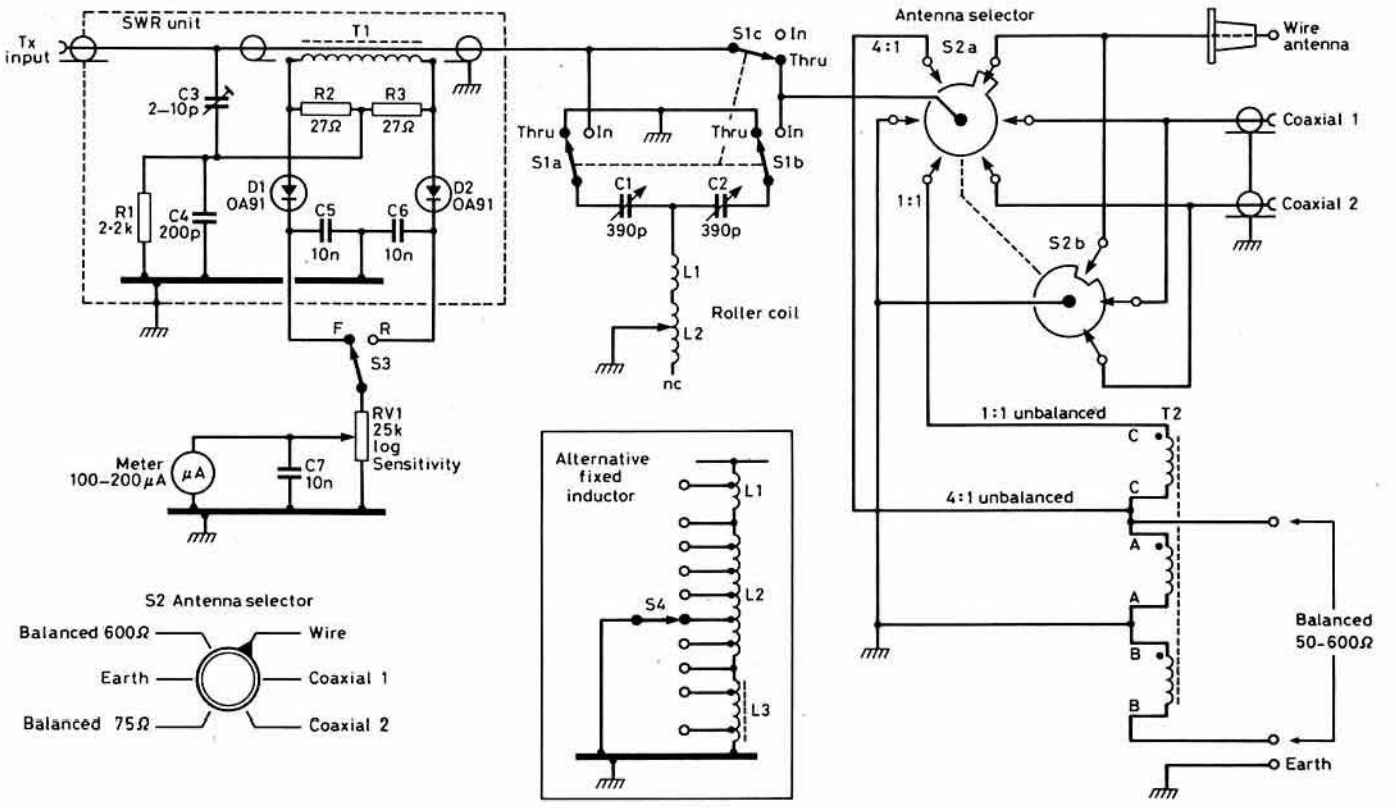


Fig 2. Circuit diagram of the unit

Balanced input

As the T-match is an unbalanced antenna tuner, some type of balun transformer must be incorporated if it is to be used successfully with balanced feeders. While a balun transformer provides a very simple solution for coupling a balanced feeder to an unbalanced tuning unit, it is not likely to be as efficient as a properly-balanced atu. On the other hand it is almost impossible to build a balanced atu to cover the wide frequency range required, so the use of a transformer makes an acceptable compromise. Many published designs, as well as a few commercial antenna tuners, commonly use a 4:1 balun either inside or fairly adjacent to the unbalanced tuner to provide a balanced input for impedances in the range 150 to 600Ω. However, if a low impedance feeder from either a G5RV or W3DZZ type of antenna is connected to a 4:1 balun, significant losses may occur. For this reason it was decided to use a 1:1 balun which, if fitted inside the tuning circuit, can easily be switched to 4:1 by use of the antenna selector switch. This now provides a range of balanced inputs from about 45 to 600Ω without introducing too many losses into the system.

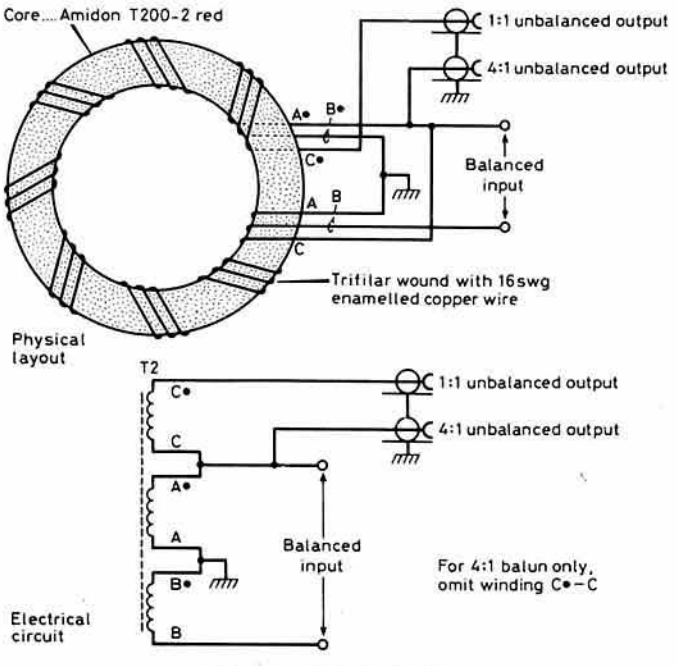


Fig 3. The balun transformer

Balun construction

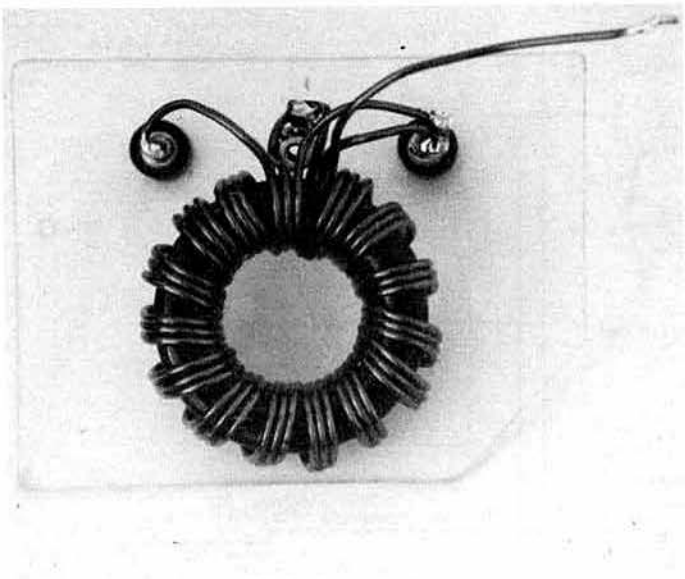
The balun transformer is wound on a single Amidon T 200-2 powdered-iron core, colour coded red. For sustained high-power operation, 400W plus, two such cores can be taped together by using plumbers ptfe tape, which can also be used to provide an added layer of insulation between the core and the windings.

Balun construction is simple, but a little cumbersome, some 14 turns of 16swg enamelled-copper wire have to be wound trifilar fashion onto the toroidal core. That is to say, three identical windings are wound on together. Care must be taken to ensure that the windings do not overlap or cross one another and that neither the core nor enamel covering is badly scratched during construction.

Fourteen turns will require approximately 38in of 16swg wire, so cut three equal lengths of 16swg wire slightly longer than required and pass all three wires through the core until they have reached about half way. This now becomes the centre of the winding and it is easier to wind from the centre to either end rather than from one end to the other which involves passing long lengths of wire through the toroid. The T200 size core will accommodate 14 turns trifilar without any overlapping of the start and finish of the winding. Close spacing will occur at the inside of the core, and a regular spacing interval should be set up on the outside. A small gap should be left where the two ends of the winding come close together.

Connection of the balun is a little more tricky and it is necessary to identify opposite ends of the same windings, which can be done with a continuity meter, with some form of tagging or colour coding being worthwhile. On the circuit diagram a dot is used to signify the same end for separate windings. It is essential that the various windings are correctly connected if the balun is to work properly. Fig 3 shows details of how the balun transformer is wound and connected. In my tuning unit, the balun is supported directly by soldering to the balanced input terminals which are spring loaded connectors. A sheet of $\frac{1}{16}$in Perspex is then used to insulate the balun from the aluminium case.

Construction of a 4:1 balun only is slightly simpler and only requires two (bifilar) windings.



The balun transformer

SWR measurement

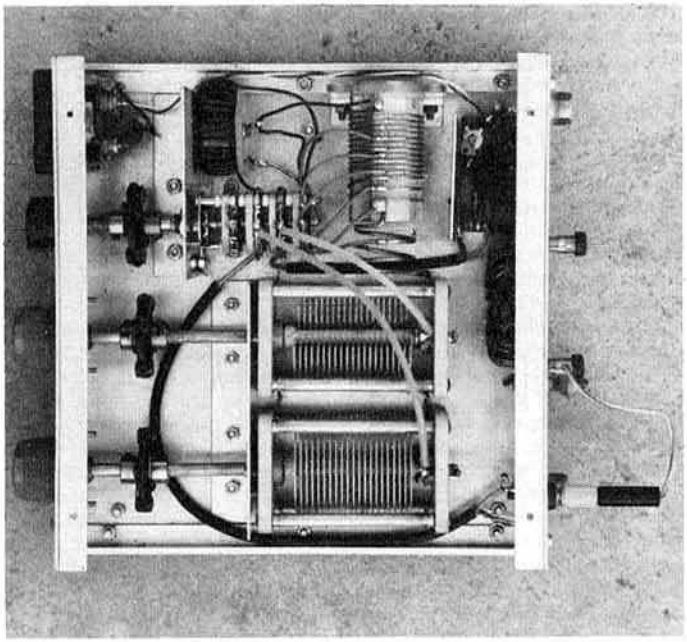
It is often convenient to be able to connect the antenna tuner directly to the transmitter without the need for extra cables and external swr bridges, so a built-in swr bridge has been included in the design. The circuit is fairly conventional and is of the current-sampling type of bridge which, unlike the voltage sampling stripline type of bridge, is not frequency conscious.

The current transformer T1 uses a small ferrite ring of about 0·5in diameter, and while the size is not critical, the grade of ferrite is. Ferrite having an A1 value of at least 125 should be used, and the Amidon FT50-43 ferrite core is ideally suited to this application.

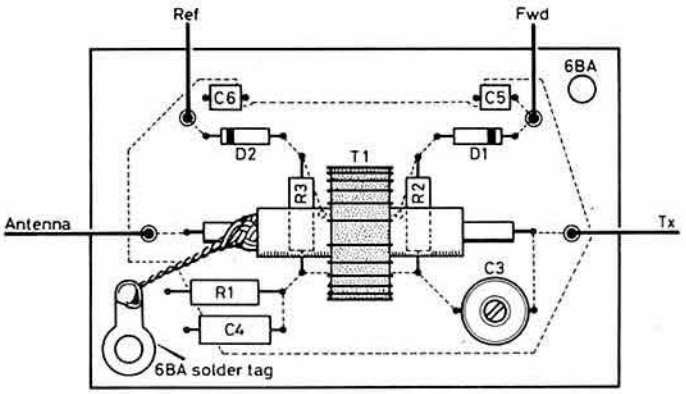
A short length of coaxial cable is passed through the ferrite core to form the primary after the 18 turn secondary has been wound on, the braid of the cable can be earthed at one end to form an electrostatic screen, but on no account should both ends of the braid be earthed or it will form a shorted turn.

The diodes D1 and D2 should be a matched pair of germanium diodes which can be selected from a number of similar type diodes by comparing their forward and reverse resistances. While this is best done with a high frequency signal, adequate matching can be achieved by using a simple multimeter.

Fig 4 gives a suggested layout and pcb track. The size is not at all critical, but a symmetrical layout should always be attempted.



Internal view of the portable version of the tuning unit with switched inductor



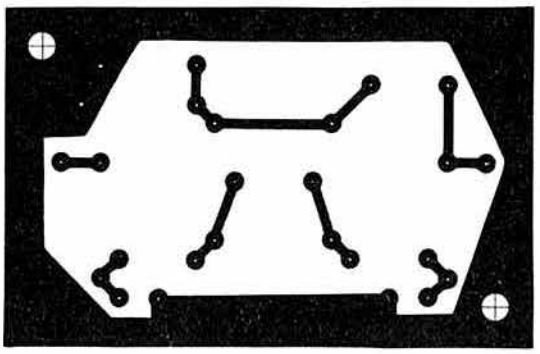


Fig 4. PCB and layout for swr bridge

The completed swr bridge should be tested away from the antenna tuner by placing it in line between a suitable transmitter and a 50Ω dummy load. The trimmer capacitor is adjusted to produce a zero-reflected reading with the forward reading at full scale. By connecting the bridge the reverse way around, some check of the diode balance can be judged by comparing the meter deflections in both directions. The forward and reverse switch selection will be reversed if the signal source is reversed through the bridge. It is advisable to check that the bridge balances on a number of different bands, as C3 may be more sensitive at the higher frequency end of the operating range.

The sensitivity of the bridge is very dependent upon the resistance of the meter used. Comparison with a calibrated swr bridge will enable a simple calibration of 1·5:1, 2:1 and 3:1 to be made, and in most cases a mental note of where these occur is the only calibration required, unless you wish to dismantle the meter in order to recalibrate the scale.

Construction of the antenna tuner

The complete tuner is illustrated in Figs 5 and 6. It is advisable to collect all the components and lay them out on a sheet of paper before committing oneself to a particular size. Layout is not over critical, but a sensible approach is needed to minimize lead lengths and unnecessary stray capacitance which could render 28MHz operation impossible. Cases can be purchased, or prefabricated using 16 or 18swg aluminium sheet bent into two interlocking "U" shapes. Half-inch aluminium angle provides stiffening as well as a means of joining the sections together. Roller coaster connections should be arranged so that minimum inductance is located at the end closest to the connections, ideally the rear of the unit. A small heavy-duty coil, L1, is included for ease of 28MHz operation and is more efficient than half a turn on the roller coil. Alternative arrangements to the roller coaster are shown in Fig 2(a) where a switched inductor is used. The switch should be of the ceramic type with substantial contacts. A third toroidal inductor is included to permit operation on 1·8MHz, and it is recommended that the bottom end of this could be shorted to ground to prevent the build-up of high voltages which could arc over.

The capacitors C1 and C2 are electrically above ground and must be mounted on insulators, a problem greatly reduced if the capacitors are constructed using ceramic end-plates. Ceramic pillars or even Perspex may be considered for mounting capacitors with metal end-plates. Additionally the shafts of the capacitors must be insulated, and the use of Eddystone spindle couplers is recommended. To ease the rather sharp tuning characteristics that can be encountered on 21 and 28MHz, slow-motion drives were tried but they made tuning on the lower frequencies rather

Components list

ATU

C1, C2	390pF 2,000V dc wkg, ceramic end-plates Eddystone or Jacksons
L1	3t 10swg, 1in id 1in long
L2	Roller coaster 36 turns, 1·5in dia, 16swg
T2	Amidon T200-2 (red) 14 turns trifilar 16swg enam
S1	Three-pole two-way ceramic Yaxley
S2	One-pole six-way double-spaced ceramic Yaxley One-pole six-way shorting wafer (one pole open)

ALTERNATIVE CIRCUIT

L1	2·5t 14swg 1in id tapped at 1·5t
L2	14t 16swg 1·25in id tapped at 0, 1, 3, 6, 9 and 14t
L3	Amidon T157-2 31 t 18swg enam tapped at 6 and 27t
S4	One-pole 11-way ceramic (three wafers to include S1 function)

SWR BRIDGE

R1	2·2kΩ
C3	2-10pF trimmer
C4	200pF mica
C5, C6, C7	10nF disc ceramic
R2, R3	27Ω
RV1	25kΩ log
D1, D2	Matched OA91 etc (germanium diodes)
T1	18t 22swg 0·5in dia ferrite ring (Amidon FT50-43, Fairite 26-43006301). Primary: 1·5in coaxial cable, braid earthed one end only to form electrostatic shield.
Meter	100-200μA
S3	SPCO miniature toggle.

Hardware to suit individual requirements
Amidon cores are available from Cirkit Holdings, Bonex and GW3TMP Electronics.
Suitable roller-coaster inductances and variable tuning capacitors are available from: CAPCO Electronics, Skelmersdale.

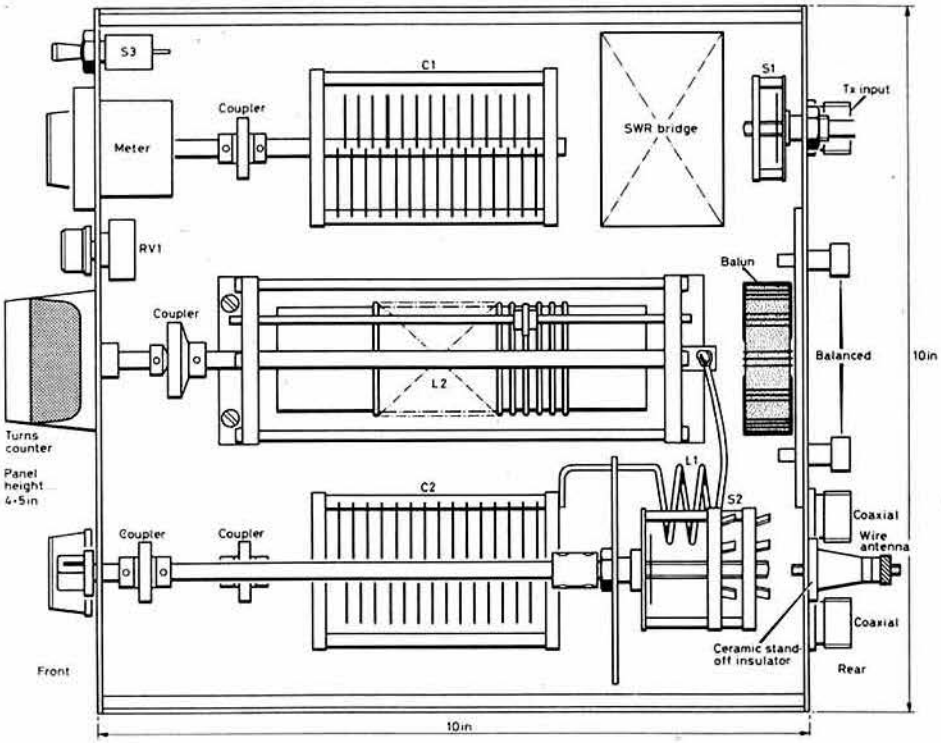


Fig 5. Antenna tuning unit layout

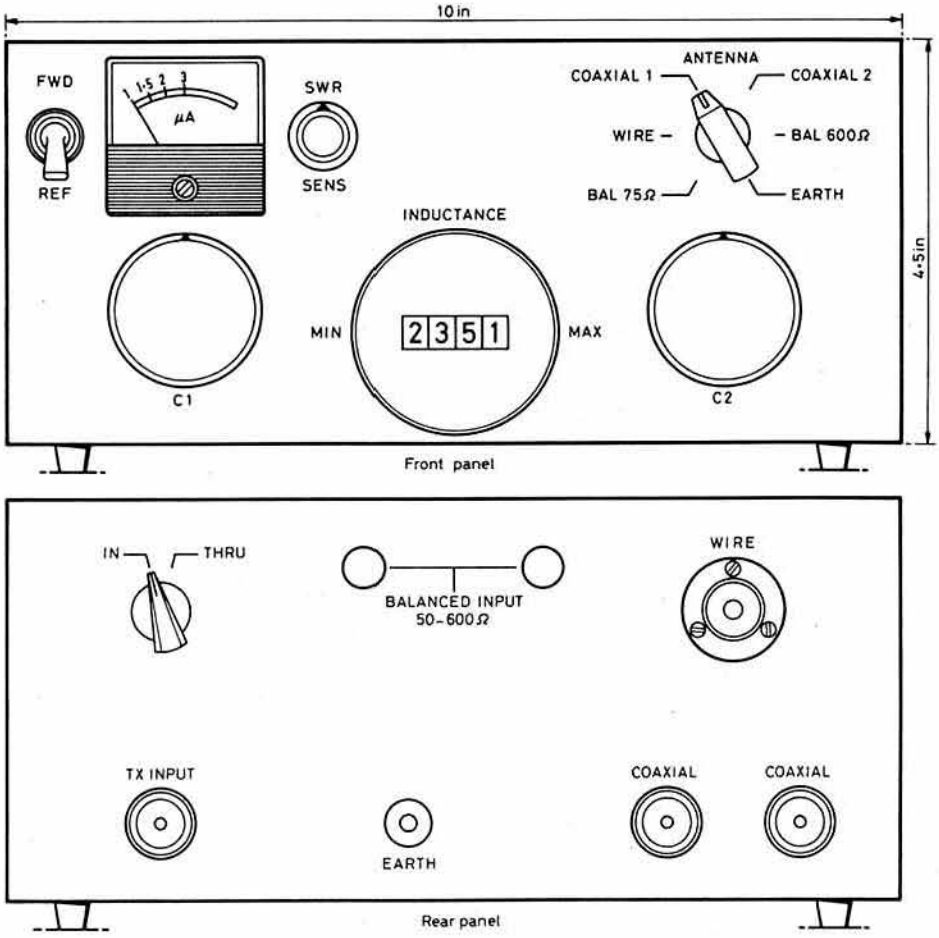
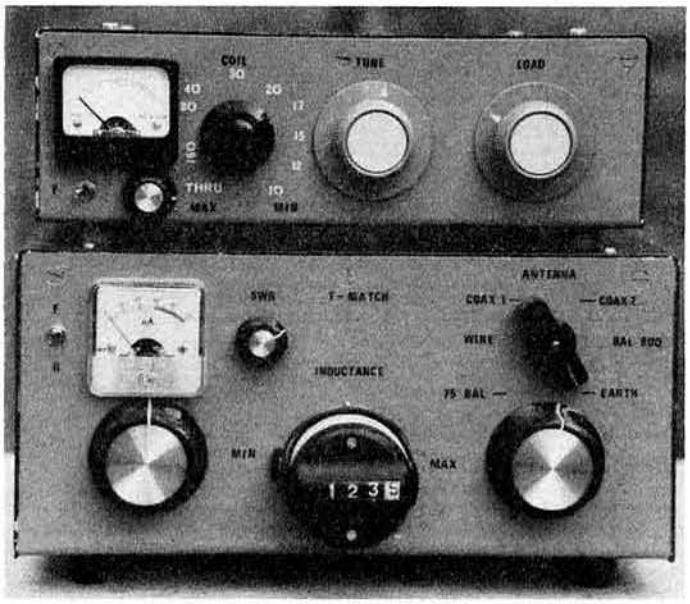


Fig 6. Front and rear panels of the unit

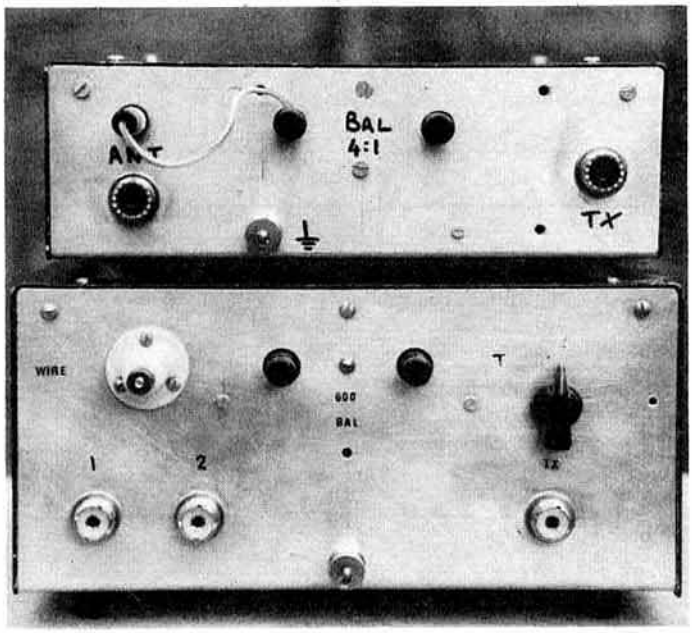


Base station and portable versions of the tuning unit

laborious and their use is not advisable. A turns counter on the roller coaster makes for much simpler operation, and may be as simple as a slot in the cabinet with a Perspex window for monitoring the position of the jockey wheel or a more sophisticated geared or direct-drive counter.

Antenna switching can introduce excessive lead lengths as well as stray capacitance, and for this reason the antenna selector switch is located on an extension shaft at the rear of the unit adjacent to the antenna inputs and the balun transformer. The wiring of the antenna switch is done strictly to achieve minimum lead lengths rather than to provide front-panel selections in any logical order. A separate IN/THROUGH switch enables the tuner to be bypassed and the antennas routed directly to the transmitter. It is located on the rear panel adjacent to the input socket to minimize lead length, and is only intended for occasional use. It is necessary to ground the tuning components in the THROUGH position to minimize capacitance effects.

Wiring of the tuner should commence after the mounting of all components, and fairly heavy wire such as 16swg tinned wire, coaxial cable inner or braid or copper strip should be used. It has not been found necessary to screen the swr bridge, but it should be located directly adjacent to the transmitter input socket and all meter leads kept away from tuning components.



Rear view of base and portable versions

The antenna selector switch has two wafers made of ceramic and is arranged so that every other contact is removed to give a double spacing. The second wafer is used for shorting and provides a ground for all unbalanced inputs when not in use, and is largely to prevent capacitative coupling to other antennas. The balanced input is grounded to dc through the balun. Balun switching is simply achieved by either taking the input from one side of the balanced input, giving a 4:1 ratio, or by selecting the third winding, giving a 1:1 ratio. An earth position enables the transmitter input to be grounded to prevent static discharge into the receiver.

Operation of the antenna tuning unit

Operation of the atu is straightforward but can occasionally baffle the uninitiated, so a simple procedure should be adopted until you are familiar with the operation of the unit. If the swr bridge is included in the design it should be checked and balanced independently of the atu, using a dummy load, and ideally be compared and calibrated against another swr measuring device of known accuracy.

To use the antenna tuner, select the required antenna and ensure that the THROUGH/IN switch is in the IN position. Set both C1 and C2 to halfway positions, adjust the inductance for maximum signal on receive, and one at a time adjust C1 and C2 for maximum receive signal. Using a small amount of carrier, further adjust C1, C2 and the inductance to eliminate any reflected readings. All tuning controls are interdependent, and settings may need to be adjusted several times before minimum swr is achieved. In addition, more than one setting may give a matched condition, in which case the settings requiring the highest value of C1 should be used. Once the transmitter is matched on low power, increase to the operating power for any final adjustments. Never attempt to tune the atu initially on full power or with a valve power amplifier that has not been tuned up.

Generally, the higher the frequency the lower the value of inductance required, but exceptionally high impedances may require more inductance than expected. Capacitance values may vary considerably, and it is not uncommon on the higher frequencies for one capacitor to be very sharp and require a minimum value while the other is flat and unresponsive. Using the components recommended it is possible to match a wide range of impedances from 1·8 to 28MHz, but operation on 1·8MHz may become impossible if lower values of capacitance are used; however, fixed silver mica capacitors may be switched across C1 and C2 to compensate. Higher values of capacitor will almost certainly prevent operation on 28 and maybe 14MHz.

Conclusion

The antenna tuner described is not new or revolutionary in design, but probably represents the ultimate in flexibility. Performance is good, and probably better than many of the commercial atus currently available, and it is not inhibited by a lack of balanced input or restricted to a very narrow range of low impedances. The power handling capability of the tuner will to a large extent depend upon the impedances encountered and the spacings of the capacitors. As a rule, very high impedances should be avoided, as arcing can occur in the switching and the efficiency of the unit may well suffer. Adjustment of antenna or feeder length can remove any exceptionally high impedances that may be encountered. I use a 180ft doublet fed with an unknown length of 300Ω slotted ribbon feeder and am able to tune it to give a 1:1 swr on all amateur bands from 1·8 to 28MHz. Using Eddystone capacitors of the type recommended, the tuning unit should be capable of handling 100W into a fairly wide range of impedances up to several thousand ohms, and the full 400W into impedances up to 600Ω.

I have built two versions of the tuner using the same basic circuit, one for base station operation using a roller coaster coil, and a smaller portable version using a range of switched inductors. The portable version has a slightly different layout, largely as a result of trying several other designs, and combining the IN/THROUGH facility on the inductor switch has necessitated several wafers. The balun used in this version is also the simpler 4:1 type and is connected with a flying lead.

For those who wish to adopt the new "SPC" circuit, the value of C2 should be made approximately 200pF, and an additional similar value capacitor should be ganged to C2 and connected between the antenna side of C2 and ground. Both capacitor rotors should be connected together and the stator of the new capacitor should be grounded.

The construction of the described antenna tuning unit should be well within the capabilities of most newly-licensed amateurs, and it can represent a considerable financial saving when compared to the commercial alternative. It represents an ideal project for commencing home construction and, if necessary, the swr bridge, the balun and the switching can be omitted and the basic tuner can be built on a piece of wood, preferably varnished. □